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Pipeline Performance in Alberta 1980-1997

December 1998

Alberta Energy and Utilities Board

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1 About This Report

This report summarizes pipeline performance in Alberta from 1980 through 1997. It builds on two previous reports, *An Analysis of Pipeline Performance in Alberta* (1983), and *Pipeline Performance in Alberta* (91-G). Figures included in this report detail

- numbers and types of pipeline failures,
- measures and trends of failure rates, and
- statistics on the lengths, sizes and types of pipelines installed within the province.

The objectives of this report are to

- provide information in a way that is easily accessible and comprehensible to members of the public, industry, and government, and
- provide industry with an average standard of pipeline performance.

Inquiries about this report should be directed to the EUB Operations Group at (403) 297-6952.

2 Summary of Findings

2.1 Background

As of the end of 1997, there were approximately 266 000 km of energy-related pipelines under EUB jurisdiction in Alberta. The province's inventory of pipelines has continued to grow, averaging an annual increase of about four per cent during the 1990s.

During the 1980-1997 period, a total of 12 137 operating pipeline failures were recorded, averaging 674 failures per year. These failures were reported by 481 different operating companies.

2.2 Nature and Frequency of Pipeline Failures

Upon analysis of data provided in this report, it is evident that the *failure frequency* of Alberta pipelines, or number of failures per 1000 km of installed pipeline, remained relatively steady for most types of lines, and decreased in the case of water pipelines.

By examining average failure frequencies for 1983-1997, calculations show the following average failure frequencies for various types of lines:

Water (fresh and salt) pipelines	16.9 failures per 1000 km
Multiphase pipelines	8.1 failures per 1000 km
Sour gas pipelines	3.0 failures per 1000 km
Crude oil pipelines	1.2 failures per 1000 km
Natural gas pipelines	1.1 failures per 1000 km

By examining the same data, but only for the five year period 1993-1997, calculations show the following average failure frequencies for the various types of lines:

Water (fresh and salt) pipelines	11.5 failures per 1000 km
Multiphase pipelines	7.7 failures per 1000 km
Sour gas pipelines	1.9 failures per 1000 km
Natural gas pipelines	1.3 failures per 1000 km
Crude oil pipelines	0.8 failures per 1000 km

This and other data helped form a number of general conclusions about the nature and frequency of pipeline failures:

- Most types of pipelines have exhibited a slightly reduced average failure frequency over the last five years compared to the frequencies averaged over the last 17 years. This indicates a slight reduction in overall failure frequencies.
- About 70 per cent of operating failures occurred on water lines and multiphase oil effluent lines. Such lines are common in Alberta's oil and gas industry because of their use in gathering systems.
- Approximately 67 per cent of operating failures occurred on 60.3 or 88.9 mm (2" and 3" nominal) diameter lines. These smaller lines comprise about 39 per cent of Alberta's pipeline system and are prevalent in well-site gathering systems.
- About 26 per cent of operating failures occurred on 114.3 or 168.3 mm (4" and 6" nominal) diameter lines, which make up about 38 per cent of Alberta's pipeline system.
- Alberta's pipeline system is predominantly steel and uncoated internally.

2.3 Cause of Pipeline Failures

The total number of failures per year resulting from each *cause* remained generally constant, even in the face of the increasing inventory of pipelines. The exception was the number of internal corrosion failures, which steadily increased. This increase is particularly apparent in natural gas pipelines and, to a lesser degree, in sour gas pipelines. This report found that:

- Leaks were the primary form of failure, comprising about 87 per cent of the total number of failures. Ruptures comprised 13 per cent of all pipeline failures.
- Corrosion continued to be the major cause of leaks. Internal corrosion was responsible for approximately 50 per cent of all pipeline failures, and external corrosion for 13 per cent of all pipeline failures.
- Third-party damage continued to be the major cause of ruptures. Overall, third-party damage was responsible for about 8 per cent of all pipeline failures.
- Of all releases, 95 per cent were less than 100 cubic metres of liquid or 100 thousand cubic metres of gas.

3 Scope of Study

This report covers the performance of the 266 000 km of energy-related pipelines in the province under EUB jurisdiction, including discontinued and abandoned lines. Pipelines **not** regulated by the EUB are:

- natural gas distribution pipelines operating at less than 700 kilopascals (utility gas),
- pipelines within a refinery or processing plant/facility,
- pipelines under the jurisdiction of the National Energy Board, which include any interprovincial pipelines passing from within to outside Alberta's borders,
- pressure piping as defined by the Boilers and Pressure Vessels Safety Act,
- Alberta Environment pipelines, and
- pipelines used to convey water unless connected to a facility authorized under the *Oil and Gas Conservation Act* or the *Oil Sands Conservation Act.*

3.1 Classification of Pipelines

The EUB classifies pipelines according to substance for the purpose of collecting statistical data. If a pipeline transports more than one substance, the length is allocated to the substance of highest priority. The list below determines that, for example, a length of pipeline that batch transports propane (#2) and crude oil (#3) would be allocated to the HVP category (#2) because propane is a higher-priority substance.

1. Sour natural gas
2. HVP products (i.e., propane, ethane, butane, and combinations)
3. Crude oil
4. Oil effluent, multiphase
5. LVP products (liquid fuels)
6. Natural gas
7. Fuel gas
8. Salt water
9. Miscellaneous liquids
10. Miscellaneous gases
11. Fresh water

Certain substances have been grouped because of similar characteristics. Salt water and fresh water are combined to form the "water" category. Sweet multiphase and sour multiphase become simply "multiphase", and sweet crude oil and sour crude oil comprise the "crude oil" category. HVP products, LVP products, fuel gas, miscellaneous substances, and unknowns (some abandonments) are grouped into the "other" category.

3.2 Reporting Requirements

The *Alberta Pipeline Act* requires all operators of pipelines to report any pipeline failure to the EUB regardless of cause, magnitude, or consequence. A **pipeline failure** is defined as the failure of the pipeline to contain the substance being transported; and for statistical purposes is designated as either a **leak** or **rupture.** The EUB also requires the reporting of any accidental contact with a pipeline, even though it may not have resulted in a loss of product, and these contacts have been recorded separately since 1994. When a pipeline failure occurs, the operating company is required to inform the local EUB field office. An EUB field representative logs the information into a database. Information collected includes the date of occurrence, geographic location, pipeline specifications, general and specific operating conditions, environmental or spill details, and one of the **cause categories** shown here:

Internal corrosion	External corrosion
Weld corrosion	Construction damage
Damage by Others	Earth movement

Mechanical joint failure	Girth weld failure
Other weld failure	Miscellaneous joint failure
Seam rupture	Installation failure
Valve/fitting failure	Pipe failure
Overpressure	Operator error
Unknown	Miscellaneous

Depending on the circumstances of the failure, EUB staff may require the operating company to perform additional analysis of the failure and/or take special precautionary measures before operating the pipeline again. Often, an EUB field representative visits the failure site to do an inspection.

Volumes of product lost due to failure are either determined from metered production information where possible, or estimated on site. As a spill may have occurred quite some time before an EUB field representative or operator has the opportunity to view the area, obtaining an accurate volume can be difficult.

Pressure test failures on new pipelines that have not yet been in service are not entered into the database and are not included in EUB statistics. Failures during requalification pressure testing are included in the database. If multiple pipeline failures occur during a retest, each one is listed as a separate entry due to different land locations. Please note, however, that retest failures are **not** included in the data presented in this report because the study focuses on operating failures only.

Some minor discrepancies may exist between data presented in earlier editions of this report due to the fact that databases are "live" and have undergone occasional changes (e.g., pipeline product classification, operating status, etc.). Length and size data has been extracted from the EUB's licensing database and manually correlated with the pipeline failure database. For this reason, length and size data are presented as approximate. As in any statistical evaluation, results depend upon the accuracy of information collected. The EUB relies on the diligence and accuracy of operating companies in reporting pipeline failures.

4 Data

TABLE 1 LENGTH OF PIPELINES IN ALBERTA

	1989	1990	1991	1992	1993	1994	1995	1996	1997	% of inventory
Crude Oil	26 800	27 100	27 400	27 600	28 400	28 900	29 100	29 600	30 300	11.4
Natural Gas	120 800	125 500	130 500	133 200	136 500	147 400	154 700	159 000	163 700	61.4
Sour Gas	5 400	5 700	6 100	6 300	6 400	6 900	7 600	8 000	8 900	3.3
Water	16 400	16 700	17 100	17 500	17 800	18 500	19 000	19 300	19 600	7.4
Multiphase	30 300	31 500	32 400	33 300	34 100	35 700	37400	38 400	39 600	14.9
Others	1 600	1 700	1 900	2 300	2 400	2 500	2 600	3 200	4 300	1.6
Total	201 300	208 200	215 400	220 200	225 600	239 900	250 400	257 500	266 400	100.0

TABLE 2 INSTALLED PIPELINES, BY PIPE SIZE

Pipe size	% of inventory
60.3mm (2" nominal)	13
88.9mm (3" nominal)	26
114.3mm (4" nominal)	23
168.3mm (6" nominal)	15
219.3mm (8" nominal)	7
273.1mm (10" nominal)	4
323.9mm (12" nominal)	4
406.4mm (16" nominal)	2
>406.4mm (>16" nominal)	6

TABLE 3 INSTALLED PIPELINES, BY PIPE MATERIAL

Pipe material	% of inventory
Steel	94
Aluminum	3
Fibreglass	<2
Polyethylene	1
Vinyl	<1

TABLE 4 TYPES OF INTERNAL CORROSION PREVENTION INSTALLED IN ALBERTA'S PIPELINE INVENTORY

Pipe internal corrosion protection	% of inventory
Unprotected (bare steel)	94
Thin film polymers	2.0
Cement lining	0.6
Expanded liners	1.2
Sliplined liners	0.2
PVC liners	0.01
Unspecified or Others	2.0

5 Results and Analysis

In all the following figures:

- pipelines are grouped into six substance categories (**sour natural gas, crude oil, multiphase,natural gas, water, and others**) for the purpose of simplified data presentation,
- values presented are for operating failures only and do not include pressure retest failures,
- the "weld" cause category includes girth weld failures, weld corrosion, seam rupture, and other weld failures,
- the "other" cause category includes operator error, installation failure, miscellaneous, and unknown causes, and
- the period runs from 1980-1997, unless otherwise noted.

Figure 1 (page 12)
Figure 1 shows the total number of failures that occurred in the period 1980-1997 differentiated by reported cause of failure. Corrosion was responsible for about 63 per cent of total pipeline failures. Internal corrosion caused the majority (about 50 per cent) of failures and external corrosion accounted for 13 per cent. The next largest cause was third-party damage (8 per cent of all failures).

Figure 2 (page 13)
Figure 2 indicates the total number of failures over the period 1980-1997 differentiated by the six main pipeline substance categories. In recent years the overall number of annual pipeline failures has remained quite constant despite increasing pipeline inventory. Approximately 70 per cent of failures occurred in water and multiphase lines, a trend which remained consistent over the sampling period. The number of water pipeline failures has declined. The number of sour gas pipeline failures remained relatively constant.

Figure 3 (page 14)
Figure 3 correlates the numeric relationship between failures and actual pipeline lengths, measuring the failure frequency per 1000 km of pipeline length for the 1983–1997 period. This graph shows that each pipeline category experienced a relatively steady failure frequency, except for water pipelines where the frequency decreased noticeably beginning about 1988. The table below the chart indicates the actual number of failures per 1000 km of installed pipelines. On this basis, natural (sweet) gas pipelines experienced the lowest average number of failures, at 1.1 per 1000 km per year, followed by crude oil at 1.2, sour gas at 3.0, multiphase at 8.1, and water at 16.9 failures per 1000 km per year.

Figure 4 (page 15)
Figure 4 shows the same failure frequency relationship, except only for the period 1993–1997. It can be seen that most of the pipeline types show a relatively steady failure frequency, and that the failure frequency of water pipelines continued to decline. There is a slight increase in the failure frequency for the "other" pipelines, but as the sample population is small this category tends to fluctuate more. This can also been seen in Figure 3.

Figure 5 (page 16)
Figure 5 shows that, for most pipeline failure causes, the number of failures has been consistent over the years despite the increasing length of pipelines. This suggests that for many causes, the occurrence rate is decreasing.

Figure 6 (page 17)
Figure 6 presents the same data as Figure 5 (i.e., the total number of failures by cause) but in line graph rather than bar format. In this graph, it is apparent that internal corrosion failure frequency was increasing during the 1980s but has stabilized in the 1990s.

Figure 7 (page 18)
Figure 7 examines the causes of pipeline leaks versus pipeline ruptures and the proportion for each. In failures resulting in product loss, leaks constituted 86.8 per cent of failures and ruptures 13.2 per cent. Corrosion is the predominant cause of leaks. Third-party damage is the leading cause of pipeline ruptures. Since 1994, 191 hits were recorded, and these are not included on this graph as they did not result in either leaks or ruptures. The hits equalled 47 per cent of all recorded third-party incidents for the years 1994-1997, demonstrating that approximately half of all third party incidents resulted in a pipeline failure.

Figures 8-13
Figures 8, 9, 10, 11, 12, and 13 look specifically at the causes and number of failures for each of six product categories of pipelines.

Figure 8 (page 19)
Figure 8 shows that the number of failures in water lines dropped off and then stabilized in recent years. In the same period, the amount of produced water in Alberta increased dramatically. For example, in 1988 the province produced twice as much water as oil; by 1996, that amount had risen to approximately four times as much water as oil.

Figure 9 (page 20)
Figure 9 shows the number of internal corrosion failures for multiphase pipelines increased steadily while the number of external corrosion failures held steady. However, Figure 3 demonstrates that the failure frequency has been quite consistent.

Figure 10 (page 21)
Figure 10 shows that for crude oil pipelines the causes of failures appeared to be fairly random in nature, and that no trends were apparent.

Figure 11 (page 22)
Figure 11 shows that for sour gas pipelines, internal corrosion is the major cause of failure. External corrosion failures have declined in recent years, possibly the result of improved coatings and increased inspection. The small size of the sample population results in a fairly random distribution of other failure causes. Figure 3 showed that the overall frequency for sour line failures was quite low. Of the sour gas line failures, about 86 per cent were leaks and 14 per cent were ruptures. As the potential impacts of pipeline failure are very high, operators exercise care in operating sour lines. They use the latest technology in the fields of internal electronic inspection, metallurgy, coatings, cathodic protection, and chemical inhibition.

Figure 12 (page 23)
Figure 12 shows that the number of internal corrosion failures for natural gas pipelines has generally been increasing. However, Figure 3 demonstrates that the failure frequency has been steady.

Figure 13 (page 24)
This "other" category includes high vapour pressure liquids, low vapour pressure liquids, fuel gas, and all others. Failures in this category were relatively few and this figure shows the causes to be relatively random. Although not individually identified on this chart, there were 38 HVP pipeline failures during this time period. The largest single cause of failure was damage by others.

Figures 14-15 (page 25, 26)
Figures 14 and 15 examine the data to see how failures were distributed among different line sizes. About two-thirds of all failures occurred on the small diameter 60.3mm (2") and 88.9 mm (3") lines, which make up about 39 per cent of Alberta's pipeline system. The frequency of failures for each size of line has been steady, growing only in proportion to increased installed length. In figure 14, where data for corrosion failures only is presented, the same failure frequency pattern is apparent.

Figure 16 (page 27)
Figure 16 presents the number of pipeline incidents attributable to third-party damage. Hits have been recorded separately starting in 1994, and the data shows that about 50 per cent of third-party incidents resulted in a loss of pipeline product, usually in the form of a pipeline rupture. The large numbers of these incidents continues to concern the EUB because of the potential threat to public safety. The EUB continues to encourage oil and gas operators to become members of the Alberta One-Call system in an effort to reduce the number of pipeline contacts. The EUB also recently released a revised version of Guide 30, *Guidelines for Safe Construction Near Pipelines*, and encourages anyone involved in excavation practices to review it. Please note: the use of dashes (-) in this chart indicates "no data" rather than "zero hits," as hits only started being recorded in 1994.

Figure 17 (page 28)
Figure 17 plots the number of failures against the cumulative length of all lines and the normalized failure frequency. It is apparent that there has been a slight decline in the failure frequency when adjusted by the total length of installed lines. While the trend is small, it is a positive development.

Figure 18 (page 29)
Figure 18 summarizes the number of releases resulting from reported failures of the subject time period, and shows that water and hydrocarbon spills made up the majority. The total number is larger than adding the number of individual failures together, because one single failure can result in the release of more than one type of substance.

Figure 19 (page 30)
Although the total number is quite high, Figure 19 demonstrates that the majority of releases were small, being either less than 100 cubic metres for liquids or 100 000 cubic metres for gases. Note that this graph is presented on a log scale, and that the number of larger spills was small.

6 PIPELINE PERFORMANCE AND THE EUB FIELD SURVEILLANCE GROUP

Companies operating oil and gas facilities in Alberta are responsible for conducting their operations in accordance with all applicable regulations and requirements. In turn, the EUB has the responsibility to ensure that the regulations and requirements are well understood by industry, and that fair processes are in place to monitor compliance and apply enforcement measures for non-compliance when warranted.

The EUB Field Surveillance Group conducts inspections of pipelines and pipeline operations and collects data to determine the areas of problems and determine which require additional effort to resolve. This summarized data can be obtained from the Field Surveillance 1997-1998 Provincial Summary Report. Analysis of the data from this period identified these main problem areas:

- **Pipeline Failures** – Corrosion remains the primary cause of pipeline failures. The continued analysis of failures and corrosion mitigation programs is necessary.
- **Decommissioned Lines** – As industry is maturing, many pipelines are decommissioned, or disposed of during industry restructuring. However, licensing requirements are often not being updated and pipeline data is inaccurate.
- **Damage Prevention** – Third-party damage during ground disturbance practices is still frequent; education seminars need to be continued.
- **Compliance** – A significant portion of pipeline inspections shows unsatisfactory conditions. To reduce this, continued inspections with clearly defined enforcement actions for non-compliance are necessary.

The EUB Field Surveillance Group has formulated an Operations Plan regarding pipeline inspection that outlines the following main goals and priority actions for Field Surveillance staff:

- **Goal 1: Corrosion** – to reduce environmental and public impacts by identifying corrosion problems and enforcing mitigation in early stages of the life of the line or system.
- **Goal 2: Operations Inspections** – to conduct operations inspections to reduce environmental impacts, to enhance public safety, and to reduce potential public liabilities through operator awareness and to ensure line status accuracy.
- **Goal 3: Pipeline Hits** – to reduce incidence of pipeline hits, enhancing public and environmental safety.
- **Goal 4: Compliance** – to monitor compliance with all existing regulations to provide assurance that failures, public safety hazards, or environmental concerns are not being created.

Inquiries regarding these Field Surveillance activities should be directed to the EUB Field Surveillance Group at (403) 297-8316.

7 Other Information Resources

Additional information related to pipelines and pipeline practice in Alberta can be found in the following documents:

Pipeline-related Legislation

- Alberta Pipeline Act
- Alberta Pipeline Regulation
- Alberta Surface Rights Act
- Alberta Oil and Gas Conservation Act
- Alberta Oil and Gas Conservation Regulations
- Alberta Exploration Act
- Alberta Exploration Regulation

These documents are available from:
Queen's Printer Book store
McDougall Centre
455 - 6 Street S.W. , Calgary, Alberta T2P 4E8
Phone: (403) 297-6251

EUB Documents

EUB Interim Directives

- 96-2, *Facility Application Requirements*
- 81-3, *Minimum Distance Requirements Separating New Sour Gas Facilities From Residential and Other Developments*

EUB Informational Letters

- 98-6, *Stress Corrosion Cracking on Pipelines*
- 94-17, *Notification of Pipeline Project to Conservation and Reclamation Inspectors of Alberta Environmental Protection*
- 92-3, *Pipeline Excavation Procedures*
- 91-4, *The Use of Concrete Slabs at Pipeline Crossings of Highways and Roads*

EUB Guides

- Guide 30, *Guidelines for Safe Construction Near Pipelines*
- Guide 17-3, *Pipelines and Surface Rights*

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Calgary, Alberta T2P 3G4
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Fax: (403) 297-7040

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http://www.eub.gov.ab.ca
(The site has browsable versions of many EUB guides, reports, notices, Interim Directives, Informational Letters, Acts and Regulations)

Other Relevant Publications

- Standard Z662, *"Oil and Gas Pipeline Systems,"* Canadian Standards Association
- Standard Z169, *Aluminum Pipe and Pressure Piping Systems*, Canadian Standards Association
- Standard Z245.1, *Steel Line Pipe*, Canadian Standards Association
- OCC-1-1985, *Recommended Practice for the Control of External Corrosion on Buried or Submerged Metallic Structures and Piping Systems*, Canadian Gas Association
- OCC-2-87, *Recommended Practice for the Control of Internal Corrosion of Pipeline Systems That Transport Sour Gas*, Canadian Gas Association
- *Guide for Pipelines Pursuant to the Environmental Protection and Enhancement Act and Regulations*, Alberta Environmental Protection
- *Code of Practice for The Release of Hydrostatic Test Water from Hydrostatic Testing of Petroleum Liquid and Gas Pipelines*, Alberta Environmental Protection
- *Code of Practice for the Temporary Diversion of Water for Hydrostatic Testing of Pipelines*, Alberta Environmental Protection
- Agdex 878-1, *Negotiating Surface Rights*, Alberta Agriculture, Food and Rural Development, Farmers Advocate (available from EUB Information Services)

Canadian Standards Association publications may be ordered from:
DeMille Technical Books
815 - 8th Avenue S.W.
Calgary, Alberta T2P 3P2
Phone: (403) 264-7411

Alberta Environmental Protection documents are available from:
AEP Information Services
Main floor, 9920 - 108th Street
Edmonton, Alberta T5K 2M4
Phone: (403) 422-2079*
or check out AEP's publications website at
http://www.gov.ab.ca/env/info/infocentre

* Effective 25 January 1999 this phone number will change to (780) 422-2079

8 Charts

Figure 1: All Pipeline Failures, by Cause
12 137 Operating Failures, 1980 - 1997

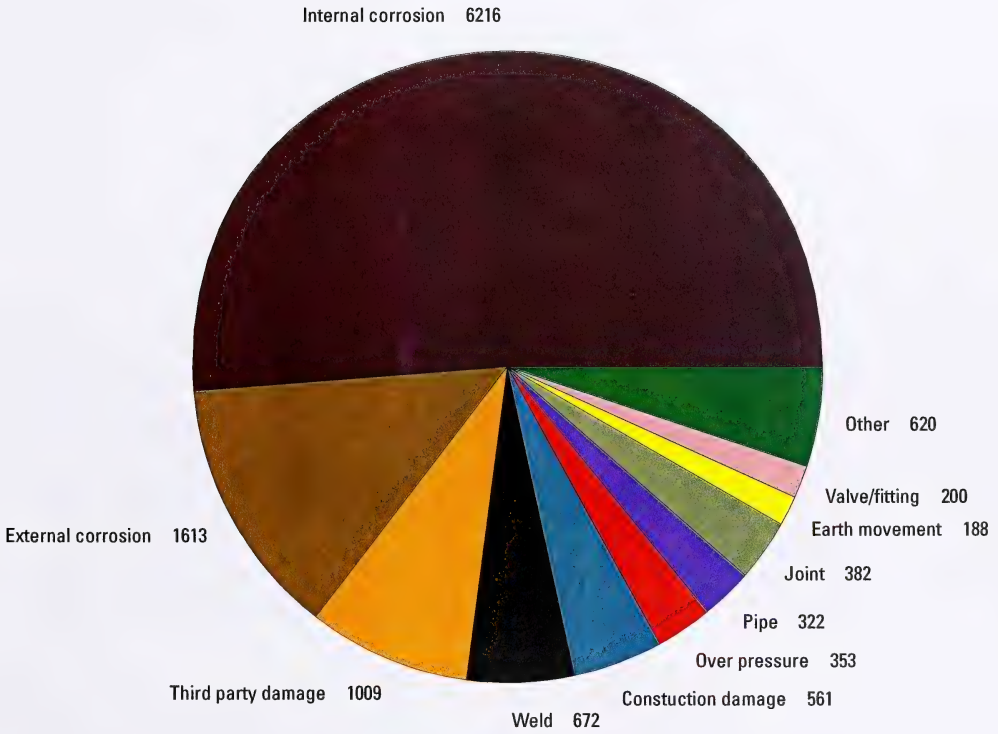
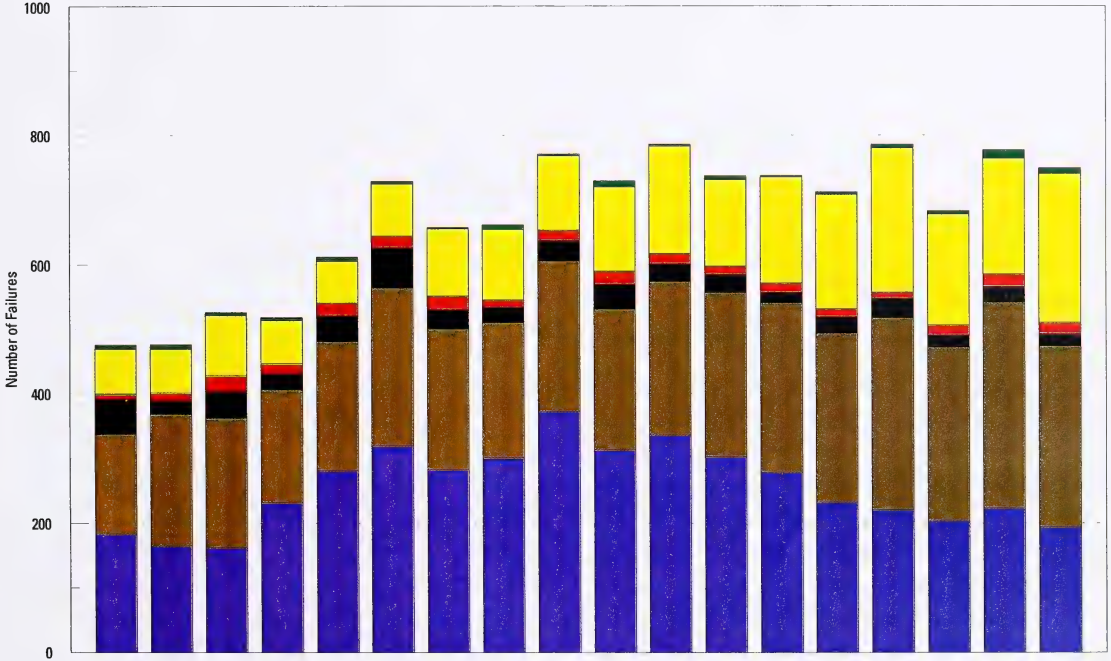


Figure 2: Total Pipeline Failures, by Product

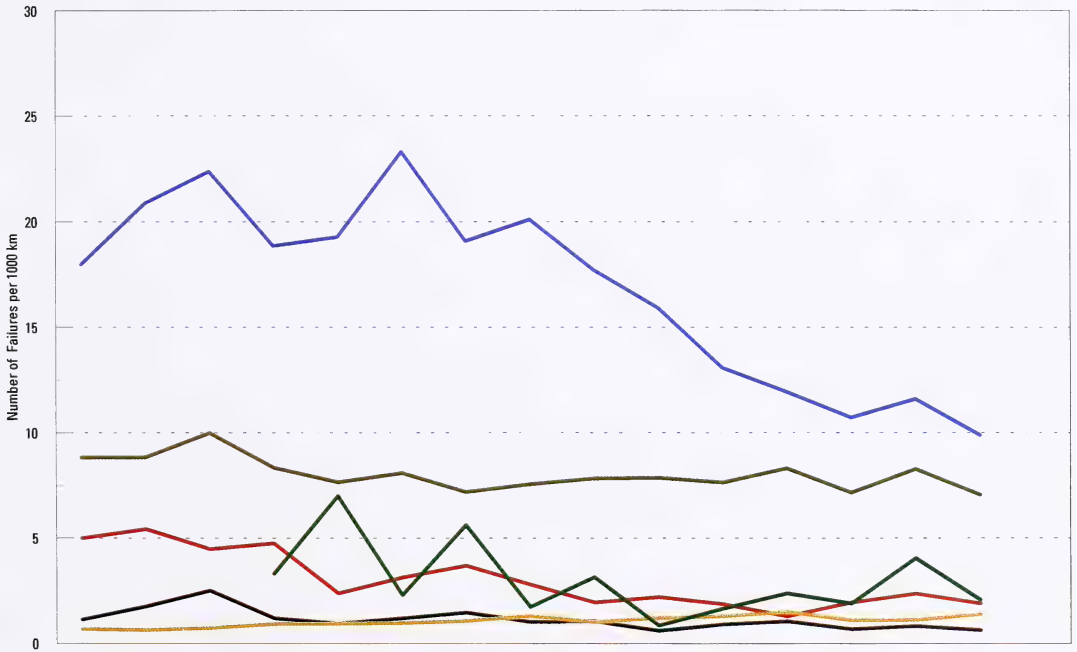
12 137 Operating Failures



Years	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97
Water	183	165	163	232	282	320	283	301	373	313	336	303	279	233	221	204	224	194
Multiphase	155	204	200	174	199	244	217	209	233	218	238	254	262	261	297	268	318	280
Crude	55	22	42	26	41	63	31	25	32	40	28	29	17	26	31	20	25	20
Sour gas	7	11	24	15	19	18	21	11	16	20	16	12	14	12	9	15	19	17
Natural gas	70	68	93	67	65	80	104	109	115	130	166	134	164	177	223	172	179	230
All other	6	7	5	5	6	4	2	7	3	9	3	6	2	4	6	5	13	9
Totals	476	477	527	519	612	729	658	662	772	730	787	738	738	713	787	684	778	750

Figure 3: Frequency of Pipeline Failures

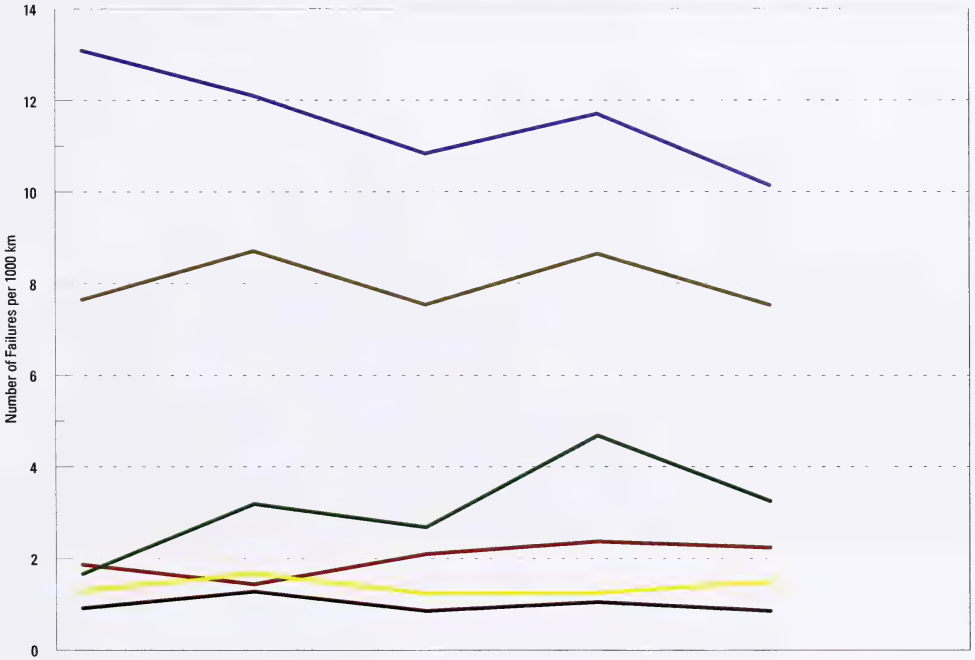
Operating Failures, by all Causes



Years	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	Avg.
Crude oil	1.15	1.77	2.53	1.21	0.96	1.21	1.49	1.03	1.06	0.62	0.92	1.07	0.69	0.84	0.66	1.15
Sour gas	5.00	5.43	4.50	4.77	2.39	3.14	3.70	2.81	1.97	2.22	1.88	1.30	1.97	2.38	1.91	3.02
Multiphase	8.83	8.84	10.00	8.35	7.66	8.09	7.19	7.56	7.84	7.87	7.65	8.32	7.17	8.28	7.07	8.05
Natural gas	0.70	0.65	0.75	0.94	0.96	0.98	1.08	1.32	1.03	1.23	1.30	1.51	1.11	1.13	1.41	1.07
Water	17.98	20.89	22.38	18.87	19.29	23.31	19.09	20.12	17.72	15.94	13.09	11.95	10.74	11.61	9.90	16.86
Others				3.33	7.00	2.31	5.63	1.76	3.16	0.87	1.67	2.40	1.92	4.06	2.09	3.02

Figure 4: Frequency of Pipeline Failures

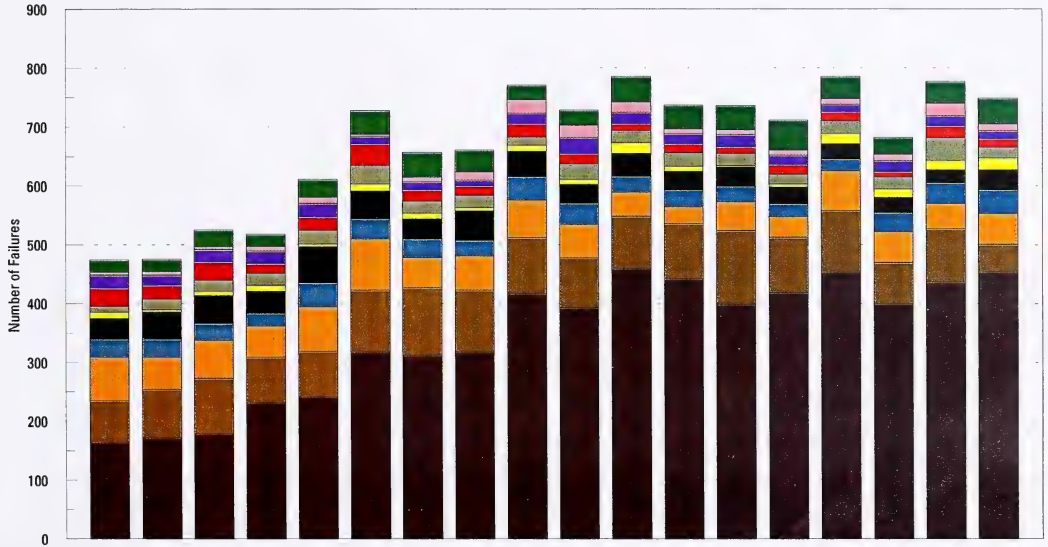
Operating Failures, by all Causes



Year	93	94	95	96	97	Avg.
Crude Oil	0.92	1.28	0.86	1.05	0.86	0.99
Sour Gas	1.88	1.45	2.11	2.38	2.25	2.01
Multiphase	7.65	8.71	7.54	8.65	7.53	8.01
Natural Gas	1.30	1.68	1.24	1.25	1.50	1.39
Water	13.09	12.11	10.84	11.71	10.15	11.57
Others	1.67	3.20	2.69	4.69	3.26	3.10

Figure 5: Total Pipeline Failures, by Cause

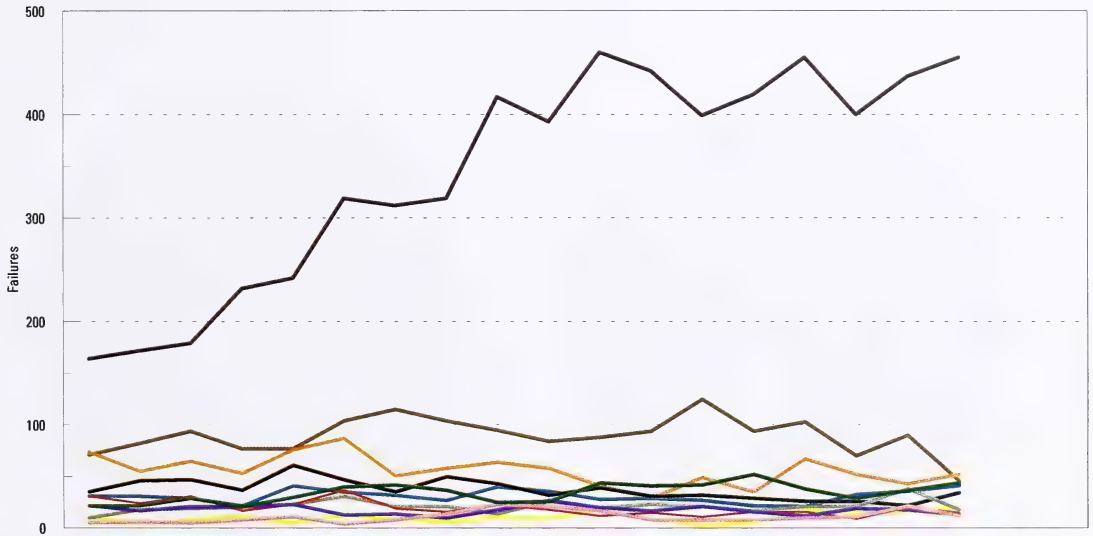
12 137 Operating Failures



Years	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97
Internal corrosion	164	172	179	232	242	319	312	319	417	393	460	442	399	419	455	400	437	455
External corrosion	71	82	94	77	77	104	115	104	95	84	88	94	125	94	103	70	90	46
Damage by others	74	55	65	53	76	87	51	58	64	58	41	29	49	35	67	52	43	52
Construction damage	31	31	29	22	41	35	32	27	40	36	28	29	27	22	21	33	36	41
Welds	35	46	47	37	61	47	35	50	43	32	39	31	32	29	26	26	22	34
Earth movement	11	4	8	11	5	12	9	6	10	9	18	9	3	5	18	14	16	20
Joints	10	18	19	20	23	31	21	21	14	26	20	23	21	17	21	21	38	18
Overpressure	31	24	31	17	23	37	19	16	23	18	12	15	11	16	16	9	20	15
Pipe failure	22	17	21	21	23	13	14	10	18	27	20	17	21	16	12	19	18	13
Valve/fitting	5	6	5	8	11	4	8	14	23	21	17	8	8	8	10	11	21	12
Other	22	22	29	21	30	40	42	37	25	26	44	41	42	52	38	29	37	44
TOTALS	476	477	527	519	612	729	658	662	772	730	787	738	738	713	787	684	778	750

Figure 6: Total Pipeline Failures, by Cause

12 137 Failures



Years	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	Total	%
Internal corr.	164	172	179	232	242	319	312	319	417	393	460	442	399	419	455	400	437	455	6 216	51.2
External corr.	71	82	94	77	77	104	115	104	95	84	88	94	125	94	103	70	90	46	1 613	13.3
Damage by others	74	55	65	53	76	87	51	58	64	58	41	29	49	35	67	52	43	52	1 009	8.3
Constr. damage	31	31	29	22	41	35	32	27	40	36	28	29	27	22	21	33	36	41	561	4.6
Welds	35	46	47	37	61	47	35	50	43	32	39	31	32	29	26	26	22	34	672	5.5
Earth movement	11	4	8	11	5	12	9	6	10	9	18	9	3	5	18	14	16	20	188	1.6
Joints	10	18	19	20	23	31	21	21	14	26	20	23	21	17	21	21	38	18	382	3.2
Overpressure	31	24	31	17	23	37	19	16	23	18	12	15	11	16	16	9	20	15	353	2.9
Pipe failure	22	17	21	21	23	13	14	10	18	27	20	17	21	16	12	19	18	13	322	2.7
Valve/fitting	5	6	5	8	11	4	8	14	23	21	17	8	8	8	10	11	21	12	200	1.7
Other	22	22	29	21	30	40	42	37	25	26	44	41	42	52	38	29	37	44	621	5.1
Totals	476	477	527	519	612	729	658	662	772	730	787	738	738	713	787	684	778	750	12 137	100.0

Figure 7: Causes of Pipeline Leaks and Ruptures
Operating Failures, 1980 - 1997

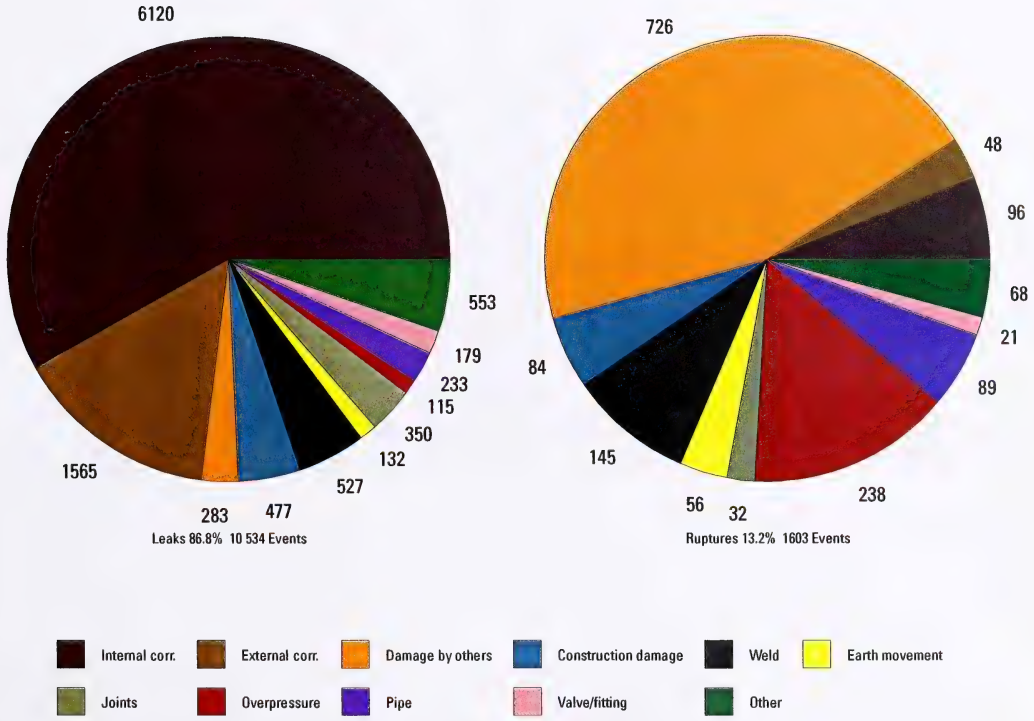
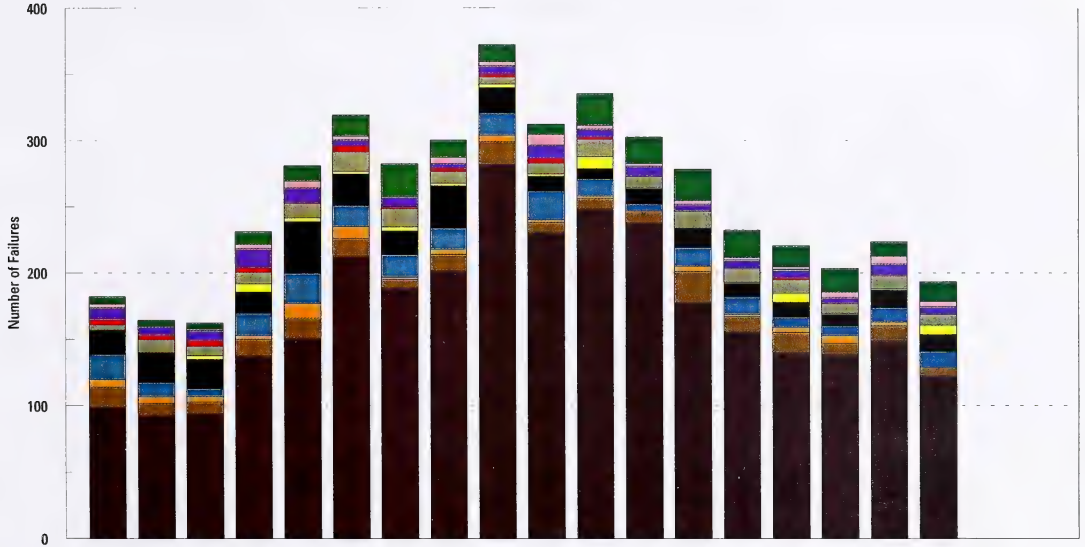


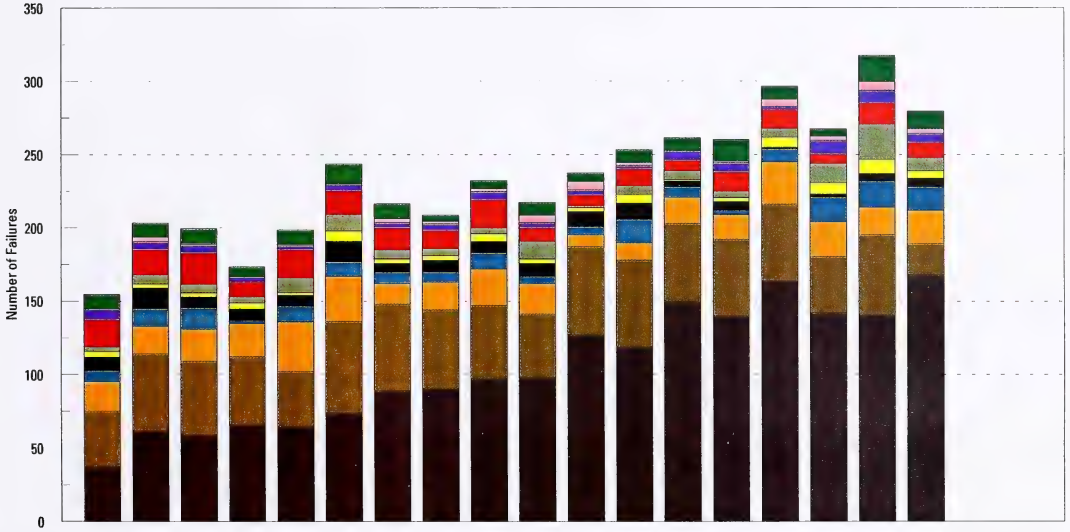
Figure 8: Water Pipeline Failures, by Cause

4609 Failures



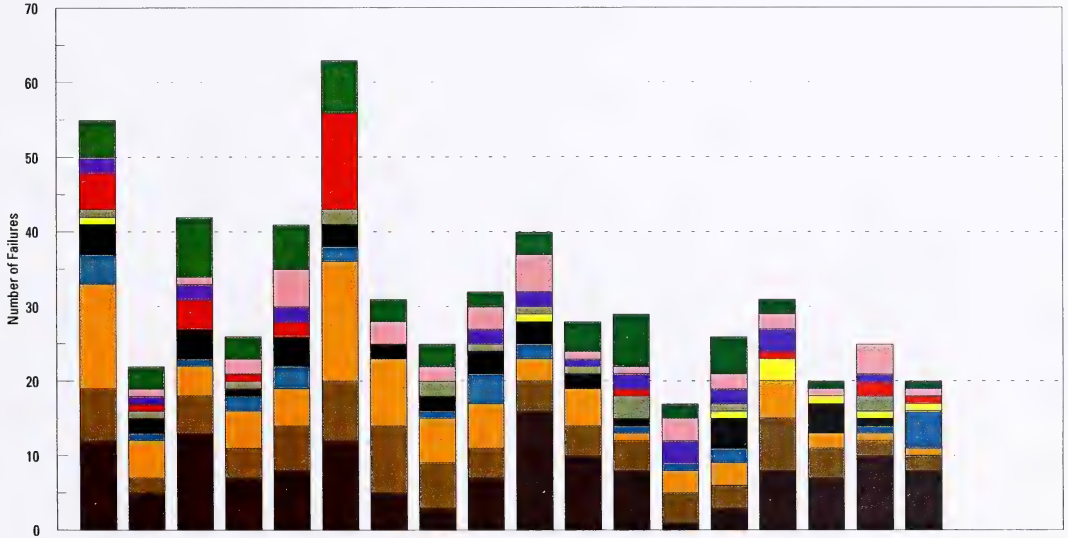
Years	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	Total	%
Internal corrosion	99	93	94	138	151	213	189	202	282	231	249	238	178	156	140	139	149	123	3064	66.5
External corrosion	15	9	9	12	15	13	6	12	17	7	7	9	23	11	15	8	11	6	205	4.5
Damage by others	6	5	4	3	11	9	2	4	5	2	2	0	4	2	4	6	3	0	72	1.6
Construction damage	19	11	6	17	23	16	17	16	17	22	13	5	14	13	8	7	11	12	247	5.4
Weld	18	22	22	16	39	24	18	32	19	11	8	12	15	10	11	9	13	13	312	6.8
Earth Movement	0	0	3	6	3	2	3	2	3	2	9	1	0	1	7	1	1	7	51	1.1
Joints	4	10	7	9	11	15	14	9	5	8	13	8	13	10	10	7	10	8	171	3.7
Overpressure	5	4	5	4	1	5	2	3	3	4	2	1	1	1	2	1	1	1	46	1.0
Pipe Failure	8	6	7	14	11	4	7	3	6	10	6	7	4	6	6	4	8	5	122	2.6
Valve/Fitting	3	0	1	3	5	3	0	5	3	8	3	2	3	2	2	4	6	4	57	1.2
Other	6	5	5	10	12	16	25	13	13	8	24	20	24	21	16	18	11	15	262	5.6
TOTALS	183	165	163	232	282	320	283	301	373	313	336	303	279	233	221	204	224	194	4609	100.0

Figure 9: Multiphase Pipeline Failures, by Cause
4231 Failures



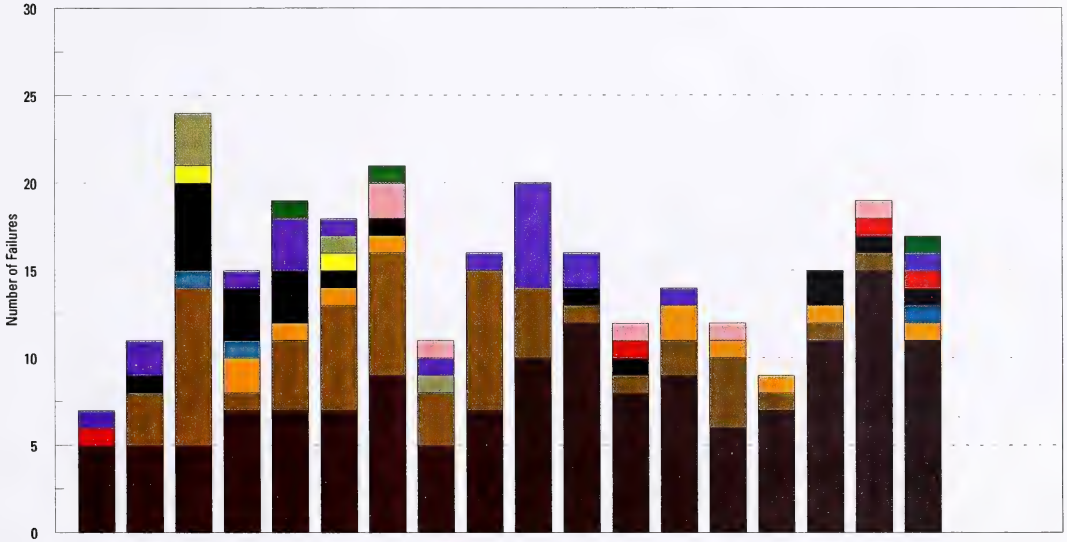
Years	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	Total	%
Internal corrosion	37	62	59	66	65	74	89	91	97	98	127	119	150	140	164	142	141	168	1889	44.7
External corrosion	38	52	50	46	37	62	59	53	50	43	60	59	53	52	52	38	54	21	879	20.8
Damage by others	20	19	22	23	34	31	14	19	25	21	8	12	18	17	29	24	19	23	378	8.9
Construction damage	8	12	15	2	11	10	8	7	11	5	6	16	7	3	9	17	18	16	181	4.3
Weld	9	14	7	8	7	14	6	8	8	9	10	11	4	6	1	2	5	6	135	3.2
Earth movement	4	3	3	4	2	7	3	3	5	3	3	6	1	3	7	8	10	5	80	1.9
Joints	3	6	6	4	10	11	6	5	4	12	1	6	6	4	6	13	24	9	136	3.2
Overpressure	19	18	22	11	20	17	16	13	20	10	8	12	8	14	13	7	15	11	254	6.0
Pipe failure	7	5	5	3	2	4	3	4	5	3	3	2	6	6	2	9	8	6	83	1.9
Valve/Fitting	0	3	1	0	1	0	3	2	2	5	6	2	0	1	5	3	6	3	43	1.0
Other	10	10	10	7	10	14	10	4	6	9	6	9	9	15	9	5	18	12	173	4.1
TOTALS	155	204	200	174	199	244	217	209	233	218	238	254	262	261	297	268	318	280	4231	100.0

Figure 10: Crude Oil Pipeline Failures, by Cause
573 Failures



Years	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	Total	%
Internal corrosion	12	5	13	7	8	12	5	3	7	16	10	8	1	3	8	7	10	8	143	25.0
External corrosion	7	2	5	4	6	8	9	6	4	4	4	4	4	3	7	4	2	2	85	14.8
Damage by others	14	5	4	5	5	16	9	6	6	3	5	1	3	3	5	2	1	1	94	16.4
Construction damage	4	1	1	2	3	2	0	1	4	2	0	1	1	2	0	0	1	5	30	5.2
Weld	4	2	4	1	4	3	2	2	3	3	2	1	0	4	0	4	1	0	40	7.0
Earth movement	1	0	0	0	0	0	0	0	0	1	0	0	0	1	3	1	1	1	9	1.6
Joints	1	1	0	1	0	2	0	2	1	1	1	3	0	1	0	0	2	0	16	2.8
Overpressure	5	1	4	1	2	13	0	0	0	0	0	1	0	0	1	0	2	1	31	5.4
Pipe failure	2	1	2	0	2	0	0	0	2	2	1	2	3	2	3	0	1	0	23	4.0
Valve/Fitting	0	1	1	2	5	0	3	2	3	5	1	1	3	2	2	1	4	1	37	6.5
Other	5	3	8	3	6	7	3	3	2	3	4	7	2	5	2	1	0	1	65	11.3
TOTALS	55	22	42	26	41	63	31	25	32	40	28	29	17	26	31	20	25	20	573	100.0

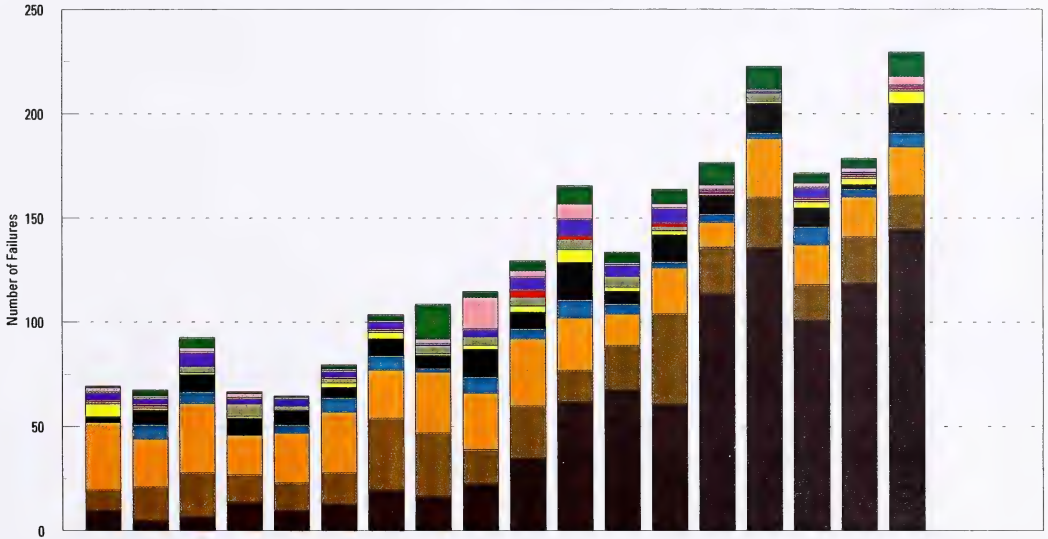
Figure 11: Sour Gas Pipeline Failures, by Cause
276 Failures



Years	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	Total	%
Internal corrosion	5	5	5	7	7	7	9	5	7	10	12	8	9	6	7	11	15	11	146	52.9
External corrosion	0	3	9	1	4	6	7	3	8	4	1	1	2	4	1	1	1	0	56	20.3
Damage by others	0	0	0	2	1	1	1	0	0	0	0	0	2	1	1	1	0	1	11	4.0
Construction damage	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	1.1
Weld	0	1	5	3	3	1	1	0	0	0	1	1	0	0	0	2	1	1	20	7.2
Earth movement	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0.7
Joints	0	0	3	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	5	1.8
Overpressure	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	4	1.5
Pipe failure	1	2	0	1	3	1	0	1	1	6	2	0	1	0	0	0	0	1	20	7.2
Valve/Fitting	0	0	0	0	0	0	2	1	0	0	0	1	0	1	0	0	1	0	6	2.2
Other	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	3	1.1
TOTALS	7	11	24	15	19	18	21	11	16	20	16	12	14	12	9	15	19	17	276	100.0

Figure 12: Natural Gas Pipeline Failures, by Cause

2346 Failures

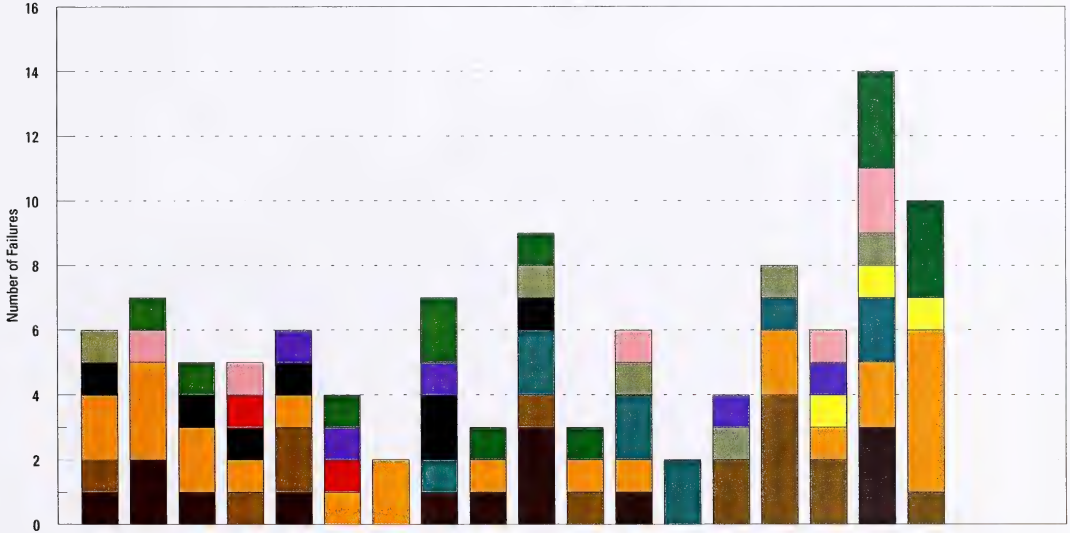


Years	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	Total	%
Internal corrosion	10	5	7	14	10	13	20	17	23	35	62	68	61	114	136	101	119	145	960	40.9
External corrosion	10	16	21	13	13	15	34	30	16	25	15	21	43	22	24	17	22	16	373	15.9
Damage by others	32	23	33	19	24	29	23	29	27	32	25	15	22	12	28	19	19	23	434	18.5
Construction damage	0	7	6	0	4	7	7	2	8	5	9	5	3	4	3	9	4	7	90	3.9
Weld	3	7	8	8	7	5	8	6	13	8	18	6	13	9	14	9	2	14	158	6.7
Earth movement	6	1	1	1	0	2	3	1	2	3	6	2	2	0	1	3	3	6	43	1.8
Joints	1	1	3	6	2	2	1	4	4	4	5	5	2	1	4	1	1	1	48	2.1
Overpressure	1	1	0	0	0	1	1	0	0	4	2	0	2	1	0	1	1	1	16	0.7
Pipe failure	4	3	7	3	4	3	4	1	4	6	8	6	7	1	1	5	1	1	69	2.9
Valve/Fitting	2	1	2	2	0	1	0	2	15	3	7	1	2	2	1	2	2	4	49	2.1
Other	1	3	5	1	1	2	3	17	3	5	9	5	7	11	11	5	5	12	106	4.5
TOTALS	70	68	93	67	65	80	104	109	115	130	166	134	164	177	223	172	179	230	2346	100.0

Figure 13: All Other Pipeline Failures, by Cause

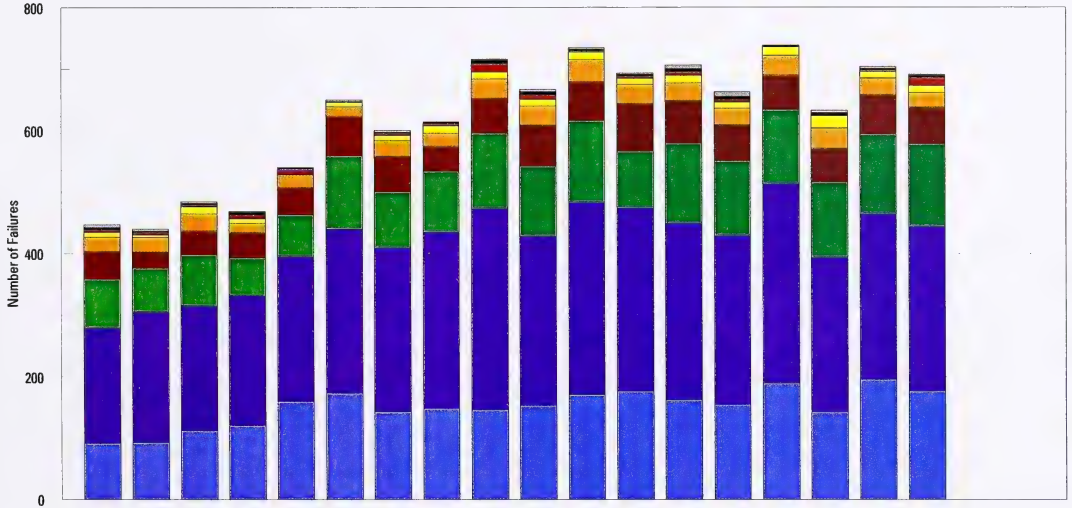
102 Operating Failures

Fuel Gas, HVP, LVP, Misc. Gas or Liquid or Solid, Unknown



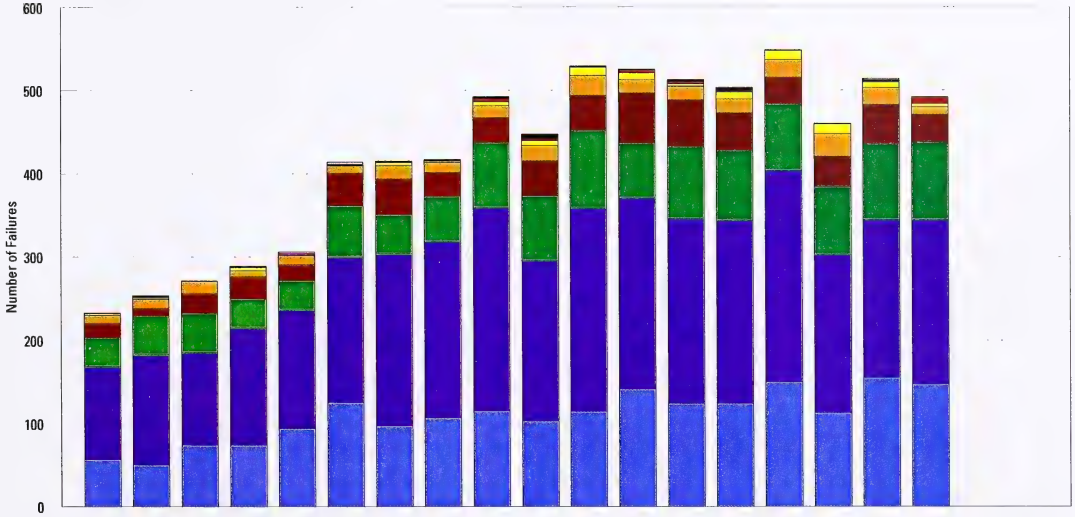
Years	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	Total	%
Internal corrosion	1	2	1	0	1	0	0	1	1	3	0	1	0	0	0	0	3	0	14	13.7
External corrosion	1	0	0	1	2	0	0	0	0	1	1	0	0	2	4	2	0	1	15	14.7
Damage by others	2	3	2	1	1	1	2	0	1	0	1	1	0	0	2	1	2	5	20	19.6
Construction damage	0	0	0	0	0	0	0	1	0	2	0	2	2	0	1	0	2	0	10	9.8
Weld	1	0	1	1	1	0	0	2	0	1	0	0	0	0	0	0	0	0	7	6.9
Earth movement	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	3	2.9
Joints	1	0	0	0	0	0	0	0	0	1	0	1	0	1	1	0	1	0	6	5.9
Overpressure	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	2.0
Pipe failure	0	0	0	0	1	1	0	1	0	0	0	0	0	1	0	1	0	0	5	4.9
Valve/Fitting	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0	1	2	0	6	5.9
Other	0	1	1	0	0	1	0	2	1	1	1	0	0	0	0	0	3	3	14	13.7
TOTALS	6	7	5	5	6	4	2	7	3	9	3	6	2	4	8	6	14	10	102	100.0

Figure 14: Pipeline Failures, by Line Diameter
Operating Failures, by all Causes
(Selected Sizes)



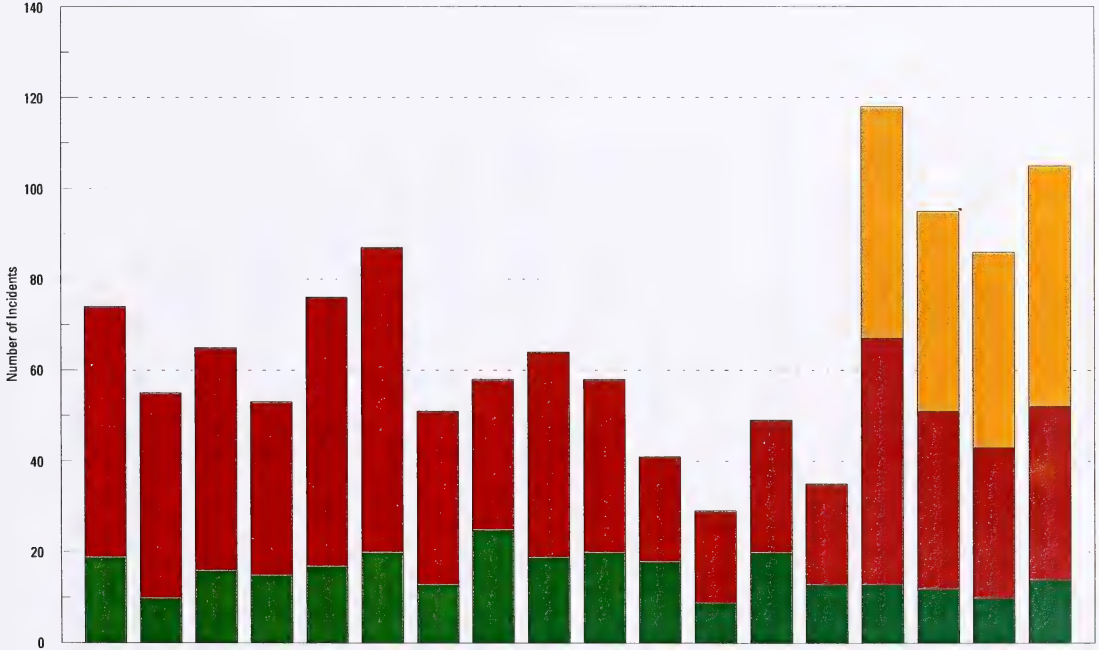
Diameter	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	Total	%
60.3 mm (2")	91	93	112	120	159	173	143	148	146	153	171	176	162	154	189	142	195	176	2703	24.1
88.9 (mm 3")	190	214	205	213	238	269	268	289	329	277	314	300	289	277	326	253	271	270	4792	42.7
114.3 (mm 4")	78	70	81	61	66	117	89	97	121	112	131	90	128	120	119	121	128	132	1861	16.6
168.3 mm (6")	45	26	40	41	45	65	59	41	57	67	64	78	70	59	57	55	65	60	994	8.9
219.1 mm (8")	23	24	27	15	21	15	25	21	31	31	35	31	28	26	31	33	26	24	467	4.2
273.1 mm (10")	8	4	12	8	1	8	9	12	12	11	13	10	13	11	15	21	11	11	190	1.7
323.9 mm (12")	5	5	4	6	5	0	4	4	13	8	2	4	6	4	1	1	3	14	87	0.8
355.6 mm (14")	0	0	0	1	3	0	0	0	2	0	0	0	1	0	0	0	1	0	8	0.1
406.4 mm (16")	3	1	2	3	2	1	1	2	4	5	3	3	4	5	0	4	1	3	47	0.4
>406.4 (mm 16")	5	4	3	2	1	3	3	1	2	4	3	2	6	8	1	4	3	2	57	0.5
TOTALS	448	441	486	470	541	651	601	615	717	668	736	694	707	664	739	634	704	692	11206	100.0

Figure 15: Pipeline Failures, by Line Diameter
Operating Failures, by Combined Internal, External, and Weld Corrosion (Selected Sizes)



Year	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	Total	%
60.3 mm (2")	57	50	74	74	94	125	97	107	115	103	114	141	124	124	150	113	155	147	1964	25.7
88.9 (mm 3")	112	133	112	141	143	175	207	212	245	193	245	230	222	220	254	190	190	198	3422	44.8
114.3 (mm 4")	35	47	47	35	35	62	47	54	78	78	93	66	87	84	80	82	91	93	1194	15.6
168.3 mm (6")	17	9	24	27	19	39	43	29	30	42	42	60	56	45	32	36	47	33	630	8.2
219.1 mm (8")	10	11	14	7	11	9	16	12	14	18	24	16	16	17	21	27	20	9	272	3.6
273.1 mm 10")	2	2	1	4	1	1	4	2	5	6	10	8	3	8	11	12	7	4	91	1.2
323.9 mm (12")	1	1	0	0	2	0	1	1	4	3	1	4	3	2	1	1	2	9	36	0.5
355.6 mm (14")	0	0	0	0	2	0	0	0	1	0	0	0	1	0	0	0	1	0	5	0.1
406.4 mm (16")	0	1	0	1	0	1	0	1	1	4	1	1	1	3	0	0	0	0	15	0.2
>406.4 (mm 16")	0	1	0	1	0	3	1	0	1	1	0	0	1	1	0	0	2	0	12	0.2
TOTALS	234	255	272	290	307	415	416	418	494	448	530	526	514	504	549	461	515	493	7641	100.0

Figure 16: Pipeline Incidents, Due to Damage by Others
1199 Incidents



Years	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97
Leaks	19	10	16	15	17	20	13	25	19	20	18	9	20	13	13	12	10	14
Ruptures	55	45	49	38	59	67	38	33	45	38	23	20	29	22	54	39	33	38
Hits	—	—	—	—	—	—	—	—	—	—	—	—	—	—	51	44	43	53
TOTAL	74	55	65	53	76	87	51	58	64	58	41	29	49	35	118	95	86	105

Figure 17: Pipeline Failures vs. Cumulative Pipeline Length vs. Failure Frequency

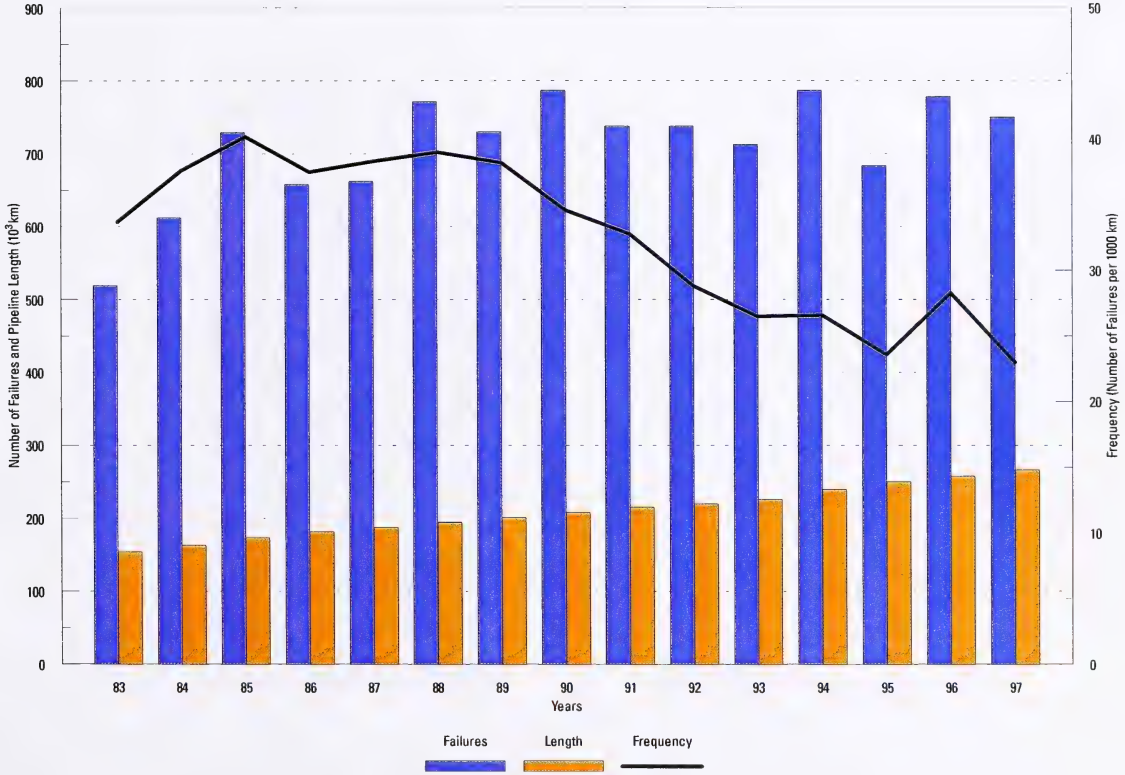


Figure 18: Number of Pipeline Releases
1980 - 1997

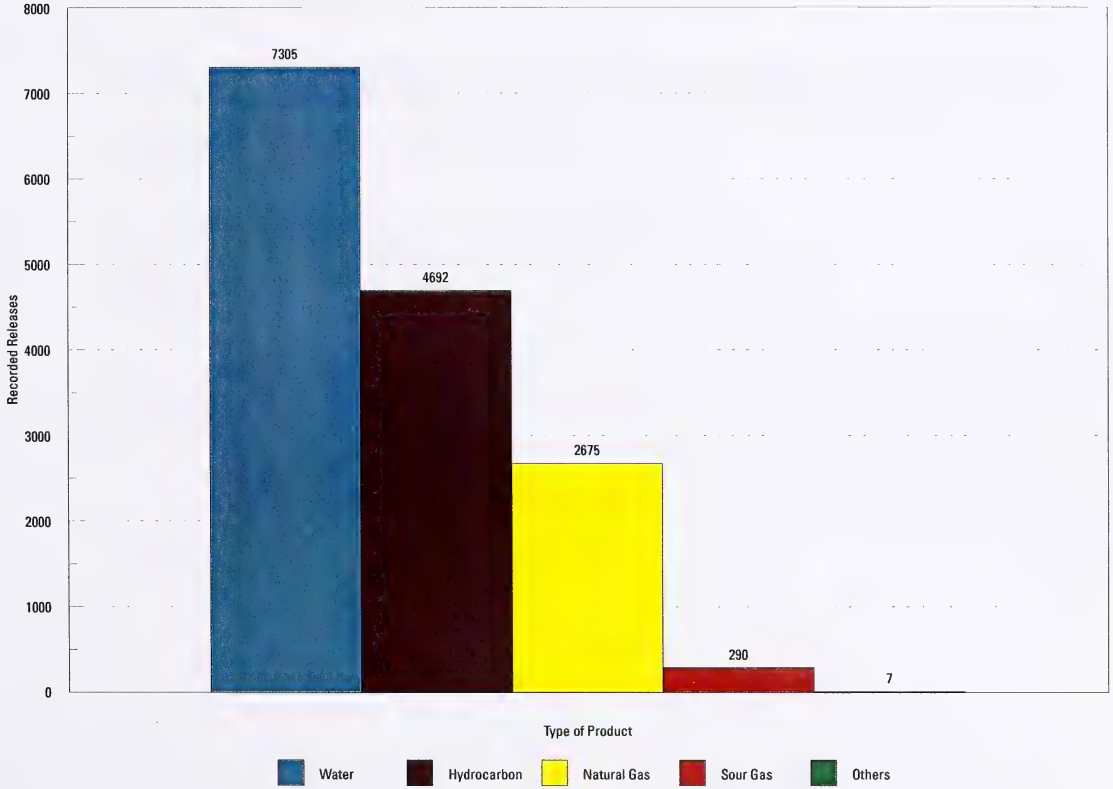
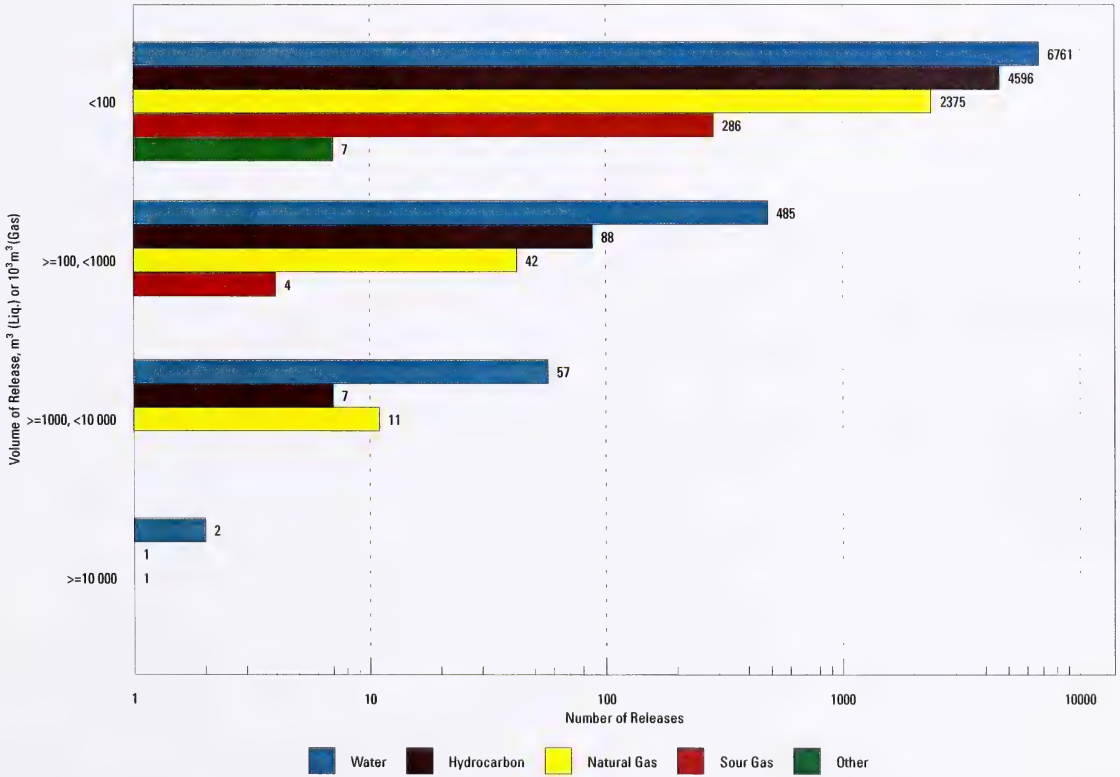


Figure 19: Number of Pipeline Releases, by Volume

1980 - 1997

Liquids in m^3, Gases in 10^3m^3



9 Glossary

Abandonment: The permanent deactivation of a pipeline or part of a pipeline, whether or not it is removed.

Cathodic protection: The process of providing corrosion control by impressing an electric current onto a structure which prevents the natural electrochemical corrosion reaction.

Chemical inhibition: The process by which corrosion of a metallic structure may be reduced or eliminated by the addition of special chemicals ("inhibitors") to the process stream.

Construction damage: Damage caused by defective construction techniques, such as dents and scrapes by mechanical devices, disbonding or damage of internal or external coatings during construction, failure due to settling of pipe (improper backfill), and failure at bends due to construction practices, but excluding damage by others during construction.

Crude oil: A mixture comprised mainly of pentanes and heavier hydrocarbons that may be contaminated with sulphur compounds, that is recovered or is recoverable at a well from an underground reservoir, and that is liquid at the conditions under which its volume is measured or estimated.

CSA (Canadian Standards Association) Z662 Oil and Gas Pipeline Systems: The Canadian industry standard that outlines procedures for the design, construction, operation, and maintenance of oil and gas pipeline systems.

Damage by others: Damage to a pipeline after construction caused by ground disturbance activities.

Discontinue: To temporarily deactivate a pipeline or part of a pipeline, but where the license remains in effect.

Earth movement:A change in pipe ground support resulting from such causes as river changes, frost heaves, and slumping.

Failure: The inability of the pipeline to contain the fluid being transported, or the case of damage occurring to a pipeline by accidental contact.

Girth weld failure: A metal failure in the weld metal or heat-affected zone of a circumferential weld.

Ground disturbance: Defined in the *Pipeline Act* as any work, operation, or activity that results in a disturbance of the earth including; excavation, digging, trenching, ploughing, drilling, tunneling, auguring, backfilling, blasting, topsoil stripping, land levelling, peat removal, quarrying, clearing, post-pounding, or grading.

Hit: The striking a buried pipeline during a ground disturbance activity by which the pipeline or pipeline coating may be damaged, but operating integrity is maintained.

HVP (high vapour pressure) fluid: A hydrocarbon or hydrocarbon mixture in the liquid or quasi-liquid state with a vapour pressure greater than 110 kPa absolute at 38°C. (from CSA Z662) (e.g., ethane, butane, ethylene, propane).

Inhibition: See *Chemical inhibition.*

Installation failure: Failure at a compressor station, pumping station, or meter station.

Leak: A small opening, crack, or hole in the pipeline causing some product loss, but not immediately impairing the lines operation.

Lined pipe: Steel pipe lined with a corrosion resistant material. Typical examples are: thin-film coatings of plastic, thicker, free-standing plastic liners, or cement. Free-standing liners are typically polyethylene, nylon, or polypropylene. Thin-film coatings are generally epoxies, phenolics, nylons, or blends thereof.

LVP (low vapour pressure) fluid: Hydrocarbon or hydrocarbon mixture in a liquid or quasi-liquid state with a vapour pressure of 110 kPa absolute or less at 38°C. (from CSA Z662) (e.g., gasoline, diesel fuel).

Mechanical joint failure: Failure of a non-welded joint such as threaded couplings.

Metallurgy: The study of metals and metals processing; used to enhance mechanical, physical, and corrosion properties.

Miscellaneous failure: Failure resulting from erosion, rock damage, vandalism, lightning strikes, or flooding from rivers.

Multiphase fluid: Oil well effluent consisting of more than one fluid, such as oil, water, and gas.

Natural gas: A mixture of hydrocarbon and non-hydrocarbon gases, possibly in combination with liquid petroleum condensates and water.

Other weld failures: Weld failures other than girth or seam weld failure, such as weld-o-let or branch connections.

Overpressure failure: Failure caused by such events as frozen lines, waxed off lines, pig stuck in line, hydrate plug, switch failure, or thermal overpressure.

Pigging: The process of transporting an object ("pig") through a pipeline to swab out, clean, or inspect the pipeline. "Intelligent pigs" or "smart pigs" are sophisticated electronic devices passed through a pipeline that can detect and measure defects such as damage and corrosion and report their location and severity.

Pipe failure: Failure of the pipe body due to metallurgical or processing anomalies (e.g., delaminations, cracks, and voids).

Pipeline: A pipe used to convey a substance or combination of substances; includes installations associated with the pipe.

Protective coatings: Layers of non-corroding material (usually a plastic) that are applied to the exterior of a pipeline (e.g., polyethylene, asphalt, tar, tape, nylon, epoxy, or cement) to provide resistance to corrosion.

Rupture: The instantaneous tearing or fracturing of pipe material, immediately impairing the operation of the pipeline.

Seam ruptures: Failures resulting from the opening of a longitudinal weld, including those caused by vibration, but not including failures due to overpressurization.

Sour service: As defined in CSA Z662, Section 5.4.1:
a) for gas pipeline systems, service in which the hydrogen sulphide partial pressure exceeds 0.35 kPa;
b) for multiphase pipeline systems, service in which the combination of hydrogen sulphide in the gas phase and system pressure is in accordance with either of the following:

i) the system pressure is below 1400 kPa and the hydrogen sulphide content in the gas phase is above 50 mol/kmol; or

ii) the system pressure is at or above 1400 kPa and the partial pressure of the hydrogen sulphide in the gas phase is greater than 70 kPa.

Note: While the concentrations given in (a) and (b) are the normally accepted minimum concentrations at which material problems occur, the presence of other constituents in the phases making up the fluid, such as CO_2 in the gas phase and salts in the liquid phase, may cause problems to occur at lower concentrations of hydrogen sulphide.

Sour natural gas: As defined by the EUB for purposes relating to pipelines: natural gas containing more than 10 moles of hydrogen sulphide (H_2S) per kilomole of natural gas; is sometimes expressed as 1 per cent H_2S.

Third-party damage: See *Damage by others*.

Valve or fitting failures: Failures of a valve or fitting such as gasket blowouts, or pig trap failures.

Water: Fresh water - potable water, usually river, lake, or well water.
Salt water - any water other than potable (e.g., produced water).

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